Secondary School Chemistry

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Chemistry, The Central Science? The History of the High School Science Sequence

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A trademark of U.S. science education is the teaching of high school science in the fixed order: biology, then chemistry, and finally physics (B–C–P) *(1).* Somewhat baffling to non-Americans, this B–C–P sequence is found in more than 99% of high schools and is unique to the United States. Much recent debate, particularly in the physics-education community has questioned the educational wisdom of the B–C–P order and many are calling for physics to be taught earlier in the sequence—the "Physics First" movement *(2).* Recently an article in this *Journal* discussed Physics First *(3)* noting that while chemistry was considered to be the *central science,* physics was considered to be the *foundational science*. The relative merits of the Physics First or the traditional "Biology First" notwithstanding, an important first step in understanding these issues is to determine how the present B–C–P course order was established. Specifically, how and why did chemistry become the central high school science, that is, the course taught between biology and physics, and in general what impact did this placement have on the development of high school chemistry? Some answers to these questions can found by considering educational decisions made between 1890 and 1930.

Chemistry Education in Secondary Schools before 1890

Chemistry as a subject was introduced into American secondary schools in the first quarter of the 19th century *(4)* and it soon became firmly established in the curricula of many schools *(5, 6).* The subject at the time was taught exclusively by lecturing, with the textbook as the principal resource. It was not until the last quarter of that century that demonstrations and laboratory work were added *(7, 8).* Despite the inroads chemistry made into a classics dominated course of studies, it was generally viewed as having only limited educational value. Even by 1870, chemistry was not necessary for admission to any college *(9)* and students who had taken chemistry in high school were often required to repeat the subject *(10).* The quality of chemistry taught in high schools was understandably varied. Many science teachers had limited chemistry backgrounds—it was the normal practice for chemistry teachers to have taken only one general chemistry class in college *(7).*

Before 1890, there was no specific high school science sequence and chemistry could be taught in any grade. The only discernible pattern was that in schools that offered both physics and chemistry, the physics class usually preceded the chemistry class *(11).* Data collected in 1892 showed that in a sample of 40 high schools, chemistry was offered in only 28 of them *(12).* While 60% of the high schools that offered chemistry had one-year courses, their time allocation varied from 68 hours/year (2 periods/week) to 358 hours/year (2 periods/day). Of the remaining schools 20% offered chemistry as part-year courses, while 20% offered chemistry as a two-year course. This lack of standardization was not confined to chemistry but was common for all other subjects and led to the creation of a national committee to address the issue. This committee, commissioned by the National Educational Association, the premier educational association of the time, became popularly known as the Committee of Ten (CoT). The CoT is often credited with establishing the B–C–P sequence, but this is an oversimplification.

The Committee of Ten

In 1892, the National Educational Association organized a committee of ten individuals, who were charged with determining what should be taught in high school so students from different schools would have a more uniform preparation for college. The CoT was chaired by Charles Eliot, a well-known chemist and the president of Harvard and also included William T. Harris, the U.S. Commissioner of Education at the time *(13, 14).* The CoT organized nine subcommittees each devoted to a different academic subject area and included Latin, Greek, English, modern languages, mathematics, and history. There were three science subcommittees, one for physical science (physics, chemistry, and astronomy), another for natural history (botany, zoology, and physiology), and a third for geography (physical geography, geology, and meteorology). All of the subcommittees were given the same questions to answer: How much time should be devoted to each subject? When and how should they be taught and assessed? What were the best methods for teaching each subject? What content should be included? Should the subject be different for college-bound students ?[1]

The physical science subcommittee was headed by another renowned chemist, Ira Remsen,[2] *(15, 16)* and included distinguished scientists and educators of the day. This subcommittee in answering the questions, made 22 recommendations to the full committee. The recommendations that were pertinent to chemistry included the following:

- That the study of chemistry should precede that of physics in high school work
- That the study of physics be pursued the last year of the high school course
- That the study of chemistry be introduced into the secondary schools in the year preceding that in which physics is taken up
- That at least 200 hours be given to the study of chemistry in the high school

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- That both physics and chemistry be required for admission to college
- That there should be no difference in the treatment of physics, chemistry, and astronomy for those going to college or scientific school and those going to neither…That in secondary schools physics and chemistry be taught by a combination of laboratory work, textbook, and thorough didactic instruction carried on conjointly and that at least one-half of the time devoted to these subjects be given to laboratory work
- That in the instruction in physics and chemistry it should not be the aim of the students to make a so-called rediscovery of the laws of these sciences

In justifying their position on the relative placement of physics and chemistry, the majority of the subcommittee wrote:

> [T]he order recommended for the study of chemistry and physics *is plainly not the logical one* [italics added], but all members with one exception…felt that the pupils should have as much mathematical knowledge as possible to enable them to deal satisfactorily with physics, while they could profitably take up elementary chemistry at an earlier stage *(13a).*

While agreeing to the placement of chemistry before physics, they did not articulate why they considered a chemistry–physics sequence to be illogical nor did they state any evidence to support their recommendation. In dissenting, Waggener, a professor at the University of Colorado, gave the minority opinion and argued that chemistry being more abstract, should follow physics:

> [I]t seems not unreasonable to suggest that the whole subject of elementary physics forms a desirable basis for the study of the elements of chemistry. On the other hand a knowledge of elementary chemistry is to but a small extent helpful in getting the knowledge of physics expected from a high school course *(13b).*

The subcommittees of all the subjects presented their recommendations to the full CoT, who then combined and coordinated them into plans for high school education. In the first stage, the CoT simply compiled the various subcommittee recommendations and included the majority recommendation that chemistry be placed in the 11th grade and physics in the 12th grade. In the second stage, the CoT "slightly modified" the offerings for the sciences. As none of the science subcommittees had recommended a science for the 9th grade, the CoT placed geography in the 9th grade and physiography and meteorology in the 12th grade. They also swapped the positions of physics and chemistry so that "the subject of physics may precede meteorology and physiography" *(13c).* In the third and final stage, further amendments were made and the CoT outlined what a high school curriculum might look like and suggested four "specific programs".[1] The science classes and the order they proposed are shown in Table 1.

At first glance, Table 1 appears confusing for its unfamiliar pattern of course offerings. The classics dominated the high school programs at the time.[1] The organizing principle for the proposed courses of study was the number of languages that students would take. Although course offerings were mostly uniform in science, according to these recommendations students might take more than one science in a school year. Brackets show that students could take half-year sequences, for instance, in the junior year students would take a half-year course in astronomy and a half-year of meteorology in the Latin-Scientific, Modern Languages, and English programs. The CoT finally recommended that physics be taught in the 10th grade and chemistry in the senior year, a P–C sequence. They rationalized this choice of science sequence by noting that, because many students did not complete high school at this time,

> [T]he Committee thought it important to select the study of the first two years in such a way that…scientific subjects should all be properly represented. Natural history being represented by physical geography, the Committee wished physics to represent the inorganic sciences of precision *(13d).*

While the CoT is often cited as being the originator of the B–C–P sequence, it can be seen in each of the suggested courses of study, chemistry was placed after physics. Note also that a course in biology was absent from the table as it did not exist as a distinct subject at the time, although there were separate courses in botany, zoology, anatomy, and physiology.

Interestingly, the CoT and its subcommittees offered three different rationales for the suggested placement of physics and chemistry. First, physics should be in the 12th grade

Table 1. Science Classes Proposed for High Schools by the Committee of Ten

Year	Type of High School Program[a]			
	Classical	Latin-Scientific	Modern Languages	English
1	Physical Geography	Physical Geography	Physical Geography	Physical Geography
2	**Physics**	**Physics** {Botany or Zoology}[b]	**Physics** {Botany or Zoology}	**Physics** {Botany or Zoology}
3	———	{Astronomy, Meteorology}	{Astronomy, Meteorology}	{Astronomy, Meteorology}
4	**Chemistry**	**Chemistry** {Geology or Physiography and Anatomy, Physiology and Hygiene}	**Chemistry** {Geology or Physiography and Anatomy, Physiology and Hygiene}	**Chemistry** {Geology or Physiography and Anatomy, Physiology and Hygiene}

[a]High school programs were organized by language requirements: Classical–three foreign languages, one modern; Latin-Scientific–two foreign languages, one modern; Modern Languages–two foreign languages, both modern; English–one foreign language, ancient or modern.

[b]Brackets indicate courses with half-year sequences.

and chemistry in 11th grade because of the mathematical maturity needed to study physics. Second, physics should be in 11th grade and chemistry in 12th grade, due to physics being a prerequisite for studying other sciences. Third, physics should be in 10th grade and chemistry in 12th grade so that all students might be exposed to physics before leaving school.

After the Committee of Ten

The Committee on College Entrance Requirements (CCER) was convened by the National Educational Association in 1896 to discuss how to implement the findings of the CoT. The committee followed the CoT proposals about sequencing and recommended that chemistry be taught after physics *(17).* For college admission they proposed that students complete 16 units of study: 4 in languages, 2 in English, 2 in math, 1 in history, *1 in science,* and 6 units of electives. These units of study would later come to be known as Carnegie Units. An assumption made by the CCER was that several of the electives taken would be in the sciences. The CoT had recommended that both physics and chemistry be required for college admission; however, the CCER with its proposal of *only one year* of science for graduation, coupled with the subjects' late appearance in the sequence, essentially made chemistry and physics electives in high school.

Many states eventually followed the CCER recommendations and so for high school students only one year of science became required for graduation. This would remain true in most states throughout most of the 20th century. Furthermore, the CoT and CCER recommendations led to another effect, unique to U.S. science education, that is, individual sciences became one-year courses, not taught over multiple years. There was some debate about offering chemistry continuously through high school, but lack of suitably qualified chemistry teachers and appropriate laboratory facilities made such proposals untenable *(18).* In contrast, high school chemistry in virtually all other countries in the world historically came to be taught over several years *(18, 19).*

In the late 1800s and early 1900s, major demographic changes were occurring in the United States. Most notably in high schools the number of students was increasing rapidly. In 1890 approximately 200,000 students were enrolled in high schools, by 1900 this population had more than doubled to over 500,000, and by 1920 there were more than 2 million students in high school *(20).* Woodhull in an address to the New York Chemistry Teachers' Club in 1917 illustrated the phenomenal growth, "we have several high schools in New York City now that have more pupils than all the United States had when I began to teach" *(21).*

The courses of study endorsed by the CoT had targeted college-bound students, but with the burgeoning high school population a smaller percentage of students were going on to college. Consequently, the courses proposed started to be viewed as unsuitable for the majority of students. This led to several important curricular developments, which would affect the science sequence.

Between 1900 and 1920 two new courses were created. General science was introduced and rapidly became the most frequently taken science subject, as it met the needs of students for whom it would be a terminal science course and it was seen as a necessary introduction to another new course—general biology *(22, 23).* The separate courses in botany, zoology, anatomy, and physiology were amalgamated into a general biology course. Given the more descriptive natures of both general science and general biology they were universally placed in the early years of high school before chemistry or physics *(24).*

In 1920, The Committee on Reorganization of Science in Secondary Schools, commissioned by the National Education Association as part of the Commission on the Reorganization of Secondary Education, included general science and general biology in their proposed four-year science sequence. The committee recommended that every high school should provide biology, chemistry, and physics courses. With regard to the sequence, they recommended that general sci-

Table 2. Recommendations about the Placement of Chemistry in the High School Sequence from Historically Significant Committees

Committee	Date	Sequence	Rationale
Committee of Ten: Conference on Physics, Chemistry & Astronomy, Majority Report	1893	C–P	Chemistry before physics because of more advanced math level needed for physics.
Committee of Ten: Conference on Physics, Chemistry & Astronomy, Minority Report	1893	P–C	Physics before chemistry because physics is foundational to chemistry.
Committee of Ten: Full Committee Report	1893	P–C	All students, even those not completing high school, should have been exposed to physics.
Committee on College Entrance Requirements	1899	P–C	Followed the recommendations of the Committee of Ten.
Committee on the Reorganization of Science in Secondary Schools	1920	B–C–P or B–P–C	No recommendations about the placement of physics and chemistry, except that they should be after biology.
Committee on Chemical Education of the American Chemical Society	1924	B–P–C or P–B–C	Chemistry should be taught in the senior year after all other sciences.
National Society for the Study of Education: Committee on the Teaching of Science	1932	B–P–C or P–B–C or P–C–B	In all possible sequences physics would precede chemistry.
Harvard Committee. General Education in a Free Society	1945	B–C–P or B–P–C	Biology should precede physics and chemistry. No specified order for either of these.
American High School Today. A First Report to Interested Citizens.	1959	B–C–P	Recommendation followed the prevalent practice of the day.

ence and biology should be offered in 9th and 10th grades respectively, with chemistry and physics in either the 11th or 12th grade. The committee approved the practice in small high schools of alternating physics and chemistry in successive years *(25)*. The general practice in the majority of schools at this time was still to offer physics before chemistry *(26)*.

By 1930 there was still no established order for physics and chemistry *(27)*, though biology had become firmly established as first in the sequence. Over the next few decades, recommendations were made by other committees *(28)* about the sequence of the sciences in high school (Table 2). With the exception of the majority of the physical science section of the CoT, by World War II no committee had actually recommended that chemistry be placed before physics. But in the schools between 1890 and 1945 chemistry would find a definite position before physics.

Science Courses Offered in High Schools

Surprisingly, the recommendations of the various committees seemed to have little effect on the practice in the schools. In 1906, Dexter *(29)* completed a survey study to determine what impact the CoT recommendations were having on schools. He noted that the vast majority of schools were teaching chemistry after physics. The order, however, seemed to be determined by the year in which the latter subject came. When chemistry was a third-year subject, physics was a second-year, with the same relation between the subject in the fourth and third years *(29a)*.

Over the next few decades, Hunter conducted a series of surveys across the country, investigating the order in which the sciences were being taught in the high schools *(26, 27, 30, 31)*. Table 3 summarizes the results for the years 1908, 1923, 1930, and 1941 and shows the percentage of physics and chemistry courses that were being offered in the junior and senior years. Over these decades, physics and chemistry swapped positions in the course order. At the beginning of the century fewer chemistry courses were offered in the junior year than in the senior year. Physics had the opposite pattern. By the early 1930s physics became more frequently offered in the 12th grade and chemistry more frequently offered as an 11th grade course. Unlike biology, which was recommended as the first course in the science order by virtually all committees, the relative placement of chemistry and physics was left unspecified. The swapping of the order of chemistry and physics was not the result of any specific educational, scientific, or historical decision. No committee proposed placing chemistry before physics, nor was there any discussion of the relative merits of various sequences by these committees, though as can be seen from the Hunter studies it was the practice that evolved in the schools over this time period. Indeed, the change-over was slow and erratic and different states adopted different practices as Hunter noted in 1931:

> In Pennsylvania, Michigan, Indiana, Massachusetts, Ohio, California, Wisconsin, Washington, and Oregon there is a definite tendency toward chemistry in 11th and physics in the 12th year. In Connecticut, New Jersey, New York, Illinois, Iowa, Missouri, Colorado, and Montana there seems to be fairly well established the reverse sequence of physics in the 11th and chemistry in the 12th year *(27a)*.

Table 3. Percent of U.S. High Schools that Offer Physics or Chemistry Courses in Grades 11 and 12

Year	11th Grade		12th Grade	
	Chemistry	Physics	Chemistry	Physics
1908	37.5	55.4	57.6	33.7
1923	48.1	50.0	50.1	46.9
1930	58.0	41.8	33.8	56.7
1941	57.0	41.9	41.6	56.2

NOTE: Data are given as percentages.

To confirm the results of his survey, Hunter visited "important schools" in 22 states and reported that "there is no agreement among supervisors as well as among teachers as to the proper sequence of high school chemistry and physics" *(27b)*.

Some insight into the thinking of the time can be gleaned from the writings of the American Chemical Society's Committee on Chemical Education. Chemists were mindful of the issue of the placement of chemistry in high school and its significance for the status and development of chemistry as a subject. In 1924, the ACS Committee on Chemical Education met to discuss the content of the high school chemistry curriculum *(32)*. In the first edition of this *Journal*, they advised Chemistry teachers, "to encourage chemistry being placed in the fourth year of high school after the students have had a year of general science, and a year of biological science or physics, or preferably both." This represented the prevalent attitude of the day that seniors were more mature than juniors and so more material could be covered by them. The argument was similar to that made by the majority of the physical science subcommittee of the CoT in recommending that physics be placed in the final year. Clearly in the 1920s, the science class closest to college held the most prestige. Despite this advice, the B–C–P sequence slowly gained ground so that by the late 1940s it had become the status quo.

Not unsurprisingly, given the seemingly arbitrary sequencing of physics and chemistry, the logic of the B–C–P order has been continuously challenged *(2, 33–37)*. The primary criticisms being that the sequence fails to represent the structure of modern science and that it is pedagogically inappropriate. The development of the sequence did have a major impact on the student enrollment in these high school courses.

Enrollment in the Sciences

The CoT had recommended that all students take chemistry and physics. The changing nature of the population in high schools, the setting up of an elective system, and a credit system as well as the development of biology and general science as subjects were potential factors affecting science enrollment. Figure 1 illustrates how enrollments in biology, physics, and chemistry changed from the 1890s to the1980s.

The data show the percentage of high school students enrolled in the individual sciences at any given time *(38, 39)*. An enrollment of 25% approximates to complete enrollment; that is, all students would take the subject at some point in their high school career. While the percentage of students enrolled in physics showed a dramatic decline, the percentage

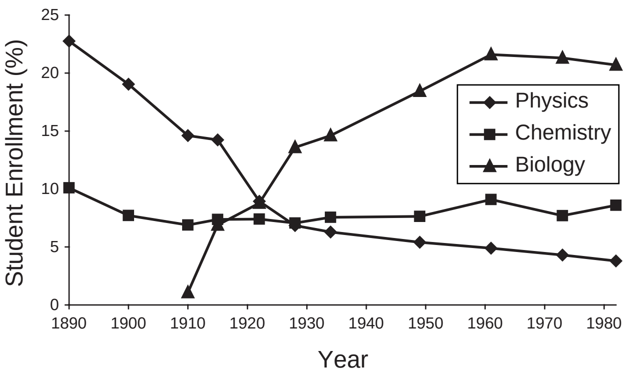

Figure 1. High school enrollment in the sciences, 1890–1982.

Table 4. Percentage of Students Graduating with Specific Science Credits from 1982 to 2000

Year	Biology	Chemistry	Physics
1982	77.4	32.1	15.0
1987	86.0	44.2	20.0
1990	91.0	48.9	21.6
1994	93.2	55.8	24.5
1998	92.7	60.4	28.8
2000	91.2	62.0	31.4

enrolled in chemistry remained approximately constant at slightly less than 10% of the population. For most of the 20th century less than 40% of U.S. students graduated high school with a credit in chemistry. Biology after its formation rapidly became the most taken science. By the 1930s more students took biology than physics and chemistry combined, clearly an outcome of its placement in the science sequence. After 1930 the relative enrollments of the subjects changed only slightly, biology continued to grow, physics continued to decline, and chemistry stayed approximately constant.

After the publication of *A Nation at Risk (40)* in 1983, enrollment in the sciences started to rise. The report had called for an increase in the graduation requirement to three years of science. At the time of *A Nation at Risk*, 36 states still only required one year of science for graduation, as the CCER had recommended. By 1992 more than 40 states were requiring at least two years of science with some states in the process of moving to a three-year requirement *(41).* The percentage enrollment data for high school sciences from 1982 to the present in the years that has been collected *(42)* are shown in Table 4. At present, biology is approaching universal enrollment in U.S. high schools and the percentage of students completing chemistry has almost doubled in the last 20 years. While it is possible to take other sciences (e.g., earth science, physical science, etc.) to meet high school graduation requirements, these classes are predominantly organized around the B–C–P sequence. Due to chemistry's central position in the sequence, further increases in state science requirements will inevitably raise enrollment in chemistry.

Discussion

Chemistry became the "central science" in U.S. high schools by accident not by design. There were three important historical factors that influenced how high school science came to be sequenced and these factors had a major impact on the development of U.S. science education.

First, decisions made before 1900 established individual sciences as one-year courses. Inevitably, the sciences would have to be taught in a specific order. Chemistry, however, is not a static subject. The stunning growth of chemical knowledge in the 20th century with the development of atomic theory, bonding, acid–base theories, and so forth has naturally led to an increase in the quantity of material in introductory chemistry. This increase in material has not been accompanied by an increase in time allocation for chemistry, but instead was fitted into the preexisting time frame. Chemistry has remained a single-year course with the same curricular time allocation; consequently, the introductory chemistry course has become overpacked with content. The CoT recommendation of 200 hours of study for each high school science was made before much of present day chemistry had been developed. Today, U.S. high school chemistry attempts to cover in one short year, as evidenced by the encyclopedic texts, what students in most other countries take several years to cover. It should be hardly surprising that chemistry developed an "obsession with content" *(43)* and is still on "the killer course list" *(44).* High school chemistry teachers need more curricular time, not to cover more material, but to do what they are actually being asked to do.

Secondly, the science courses became sequenced. By the 1920s, due largely to its descriptive nature at the time, biology had consolidated its position as the first specialized science taught in high school, with most schools offering physics next and finally chemistry. By the 1930s the relative positions of chemistry and physics had changed and the B–C–P order had been established. No committee made this decision, it was simply the practice that was adopted in the schools. Both the physics and chemistry communities were vying for their subjects to be taught last in the sequence. By the late 1940s the B–C–P sequence had become the status quo. The sciences were taught as distinct, unrelated courses in this specific order. Robinson has argued that the B–C–P sequence is strictly not a sequence, as biology is not a prerequisite for chemistry, nor chemistry a prerequisite for physics *(45).* Haber-Schaim *(46)* supported this view by analyzing the concepts included in high school science texts and showed that from a conceptual point of view a physics–chemistry–biology order was more logical. A cursory glance at any introductory biology text or curriculum shows that it contains a wealth of chemistry and consequently much elementary chemistry is understandably being taught by biology teachers. While physicists are calling for Physics First *(47),* biologists could convincingly argue for Biology Last, if high school science is to be taught in a fixed order. More than 200 schools including whole school districts (e.g., San Diego) have already moved to a physics-first order *(48).* It seems likely that this number will continue to grow, even though such a change faces significant hurdles *(47).* In other countries, a B–C–P sequence did not develop and chemistry is usually taught over multiple years and is more coordinated with the other sciences.

The third factor relates to the implications of changing state science graduation requirements. As science is taught in a specific order, any increase in overall requirements significantly increases enrollment of the later offered sciences. This has had a major impact on chemistry education. With most states initially having only a one-year science graduation requirement, chemistry was an elective, taken by a fraction of the students. When the majority of states moved to a two-year requirement in the 1980s, enrollment for all sciences increased, biology essentially became a requirement and the percentage of students taking high school chemistry doubled. Today, most high school students graduate with a chemistry credit *(42).* With a significant number of states moving to a three-year requirement, chemistry will become a requirement in these states. It would appear that Remsen and Eliot's belief that all students should take chemistry is being achieved through legislation.

The impact of having a fixed high school science sequence on the U.S. science education system has largely been overlooked. If the United States is to develop a world-class science education system for the 21st century, then it is time to reconsider not only what chemistry is taught, but also when it is taught, and how much time should be devoted to it. We would suggest that re-answering the questions set by the CoT in 1892 would be a good place to start.[1]

ʷSupplemental Material

Questions asked of all subcommittees, the 22 recommendations from the Physics, Chemistry, and Astronomy Conference, and the four programs suggested for high school by the full committee are available in this issue of *JCE Online*.

Notes

1. The full list of questions, recommendations, and the programs of study from the Committee of Ten are found in the Supplemental Materials.ʷ

2. Interestingly, the profiles of Eliot and Remsen *(14–16)* published in this *Journal* do not mention their roles on the CoT.

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